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Title: PATO IHE DDT Test Series

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PATO IHE DDT Test Series

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Purpose and Scope

This report describes one aspect of our efforts for qualifying PATO as an IHE. Specifically, we tested PATO against the DDT requirements as defined by LA-UR-15-29238 IHE Material Qualification Test Series, Section 1.1. That section states: "The purpose of the DDT test is to demonstrate that an IHE material will not undergo deflagration-to-detonation transition (DDT) under stockpile-relevant conditions of scale, confinement, and material condition. Inherent in this test design is the assumption that ignition does occur, with the onset of deflagration. The test design will incorporate large margins and replicates to account for the stochastic nature of DDT events." Along with the primary goal of qualifying PATO, this is the first time this test standard has been executed, as such, we are 'testing the test' by providing details of execution, pragmatic details that could be improved, and feedback regarding scientific issues.

Methods

As required, we used 7" outer diameter steel cylinders having a 3" bore, 40" long. Ullage was also provided, as required. The requirement document suggests threaded end caps, but allows for an equivalent confinement method. We chose the latter, employing 1 ¼" all-thread rods to pull the end plates together to provide equivalent confinement. Figure 1 shows the assembly, with the heaters installed but not the top and bottom insulation. Six heater bands, 3700 Watts each (@ 208V, Chromalox PN 161090), were bound tightly to the tube. Five individual heater control boxes (LANL-built by M-6, max 10.8 kW each) powered the heaters, one for each heater band except the middle pair which were both controlled by one box. The five zones were controlled independently (top, middle top, middle, middle bottom, and bottom) with a primary and backup thermocouple for each zone. Each zone was given the same ramp rate and soak temperature, such that the five-zone system provided very uniform temperature along the axis of the tube (Figure 9). The heaters provided insulation to the tube and we added 2" ceramic insulation to the top and bottom plates. Two additional, very robust thermocouples were included as a safety back up for heating to very high temperatures to render the system safe in case of failures, unexpected behavior etc. This temperature observation scheme was consistent with the requirement. The requirement specifies the measurement of the explosive centerline temperature, but allows inference. We chose the latter, justified by knowledge/analysis that the heating rates applied would result in a uniform internal temperature profile until self-heating commenced.

Test configurations. We conducted five tests in total, with no replicates. The requirement document specifies three replicates. The reasons we chose not to run the replicates will be discussed later. As required:

- ***Test #1***: Heat production density PATO (ρ_0 = 1.70-1.71 g/cc, 36x 3" x 1" pellets) at 20 °C/hr until ignition occurred and recorded temperature of first reaction (T_c) (PDTC shot);
- ***Test #2:*** Heat production density PATO (ρ_0 = 1.70-1.71 g/cc, 36x 3" x 1" pellets) at 100 °C/hr to 50 °C below T_c, then 20 °C/hr to 10 °C below T_c, then promptly ignited (PDI shot - details of the ignition system are provided later);
- ***Test #3:*** Same dual ramp profile as above with pour-density PATO molding powder in the tube (pour density shot);
- ***Test #4:*** Same dual ramp profile as before with hand-tamped PATO molding powder in the tube (hand-tamped shot),
- ***Test #5:*** A 1/3 length tube filled with hand-tamped density PATO, intentionally detonated using a C-4 booster for the purpose of calibrating tube damage for detonating hand-tamped-density PATO (short tube shot). Figure 1 shows this tube prior to firing.

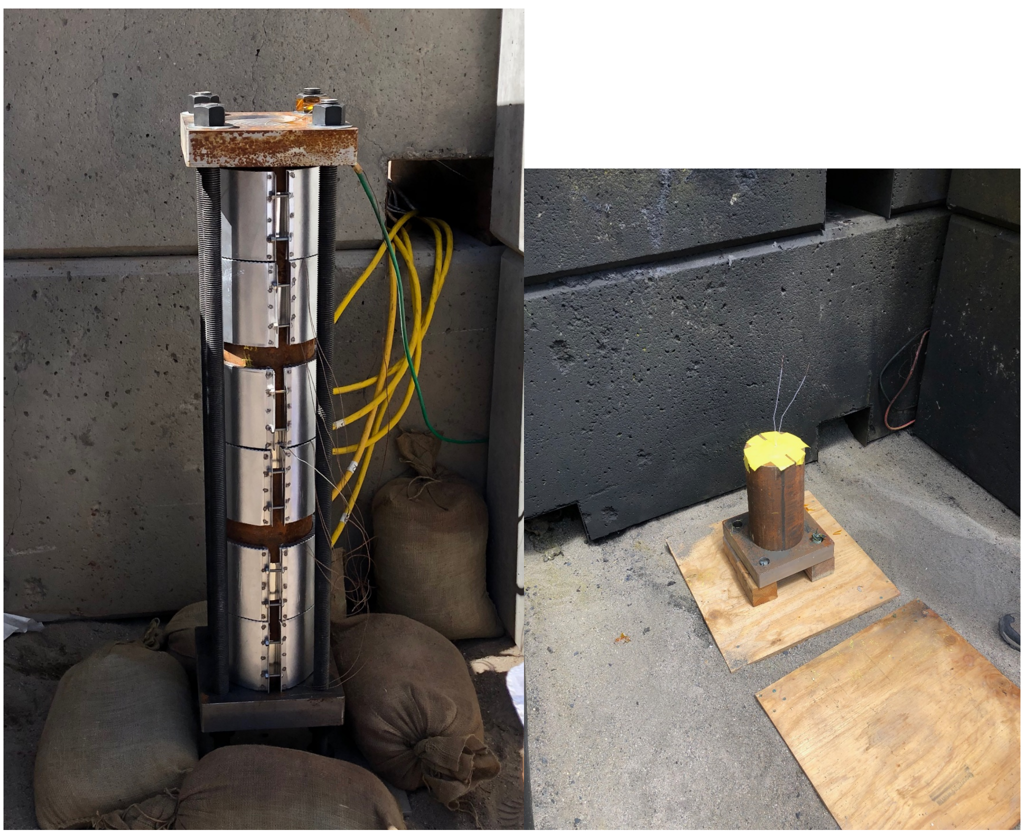

Figure 1. An assembled DDT tube containing PATO and a short tube used for detonation benchmarking.

Thermite ignition system. We employed a top-down ignition strategy out of concern that the assembly could 'go ballistic' and fly out of the arena if ignited from the bottom. Two configurations were used, both employed a diesel engine glow plug (details) energized by a constant voltage power supply (12 V, 15 A max). The power supply was set to constant voltage mode to emulate a 12 V automotive supply. The first arrangement (Configuration 1) had the glow plug threaded into the top plate such that it protruded 1.25" into the tube. The thermite used for these tests was consisted of a stoichiometric mixture of aluminum (Valimet H-2, nominal 5 µm diameter particle size) and Fe_3O_4 (Fisher Chemical, -325 mesh, 44 µm maximum particle size). A Resodyn LabRAM homogenized the mixture. In all tests, 3-5" of ullage was left between the top of the explosive and the lip of the tube. In Configuration 1, the thermite was poured on top of the explosive leaving either 0.5" (**PDI** Shot) or no ullage (**Pour Density**) between the thermite and the lip of the tube (Figure 2). This configuration allowed substantial contraction or expansion of the main explosive column while maintaining contact between the glow plug and the thermite. A measured thermal expansion of pressed PATOVA of 65-68 µm/m/°C between the temperature range 28 and 74 °C defined the ullage; the low density of thermite would compact if the PATOVA actually realized the full capability to thermally expand. This arrangement failed for the pour density shot. We believe this occurred as a result of the extremely low pour density of the PATO (~14 %TMD) and settling during heating such that the thermite charge pulled away from the igniter. The second arrangement (Configuration 2, shown in Figure 3) had the glow plug mounted to a 0.25" thick aluminum lid, which was attached to a thin walled 6.75 cm diameter x 8.0 cm height, 286 cc metal can; the can was a commercially available 16 oz paint can cut to a shorter height. A 2.54 cm hole was cut into the can bottom and covered with Kapton tape. This igniter can was filled with thermite and the aluminum plate placed snugly into the can; an interior ullage of 0.64 cm between aluminum plate bottom and thermite was left. Three protrusions were used in the aluminum plate, 1) glow plug threaded hole in the center, 2) ground return threaded hole and 3) vent hole. Kapton tape held the aluminum plate to the can. Once wired through the top plate, the can floated on top of the explosive column.

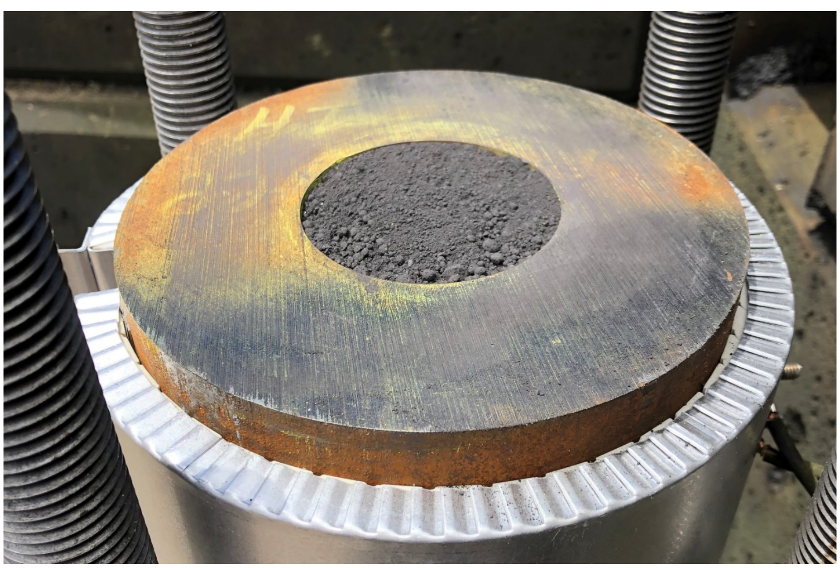

Figure 2. Thermite in Configuration 1 used in **PDI** and **Pour Density** Shots

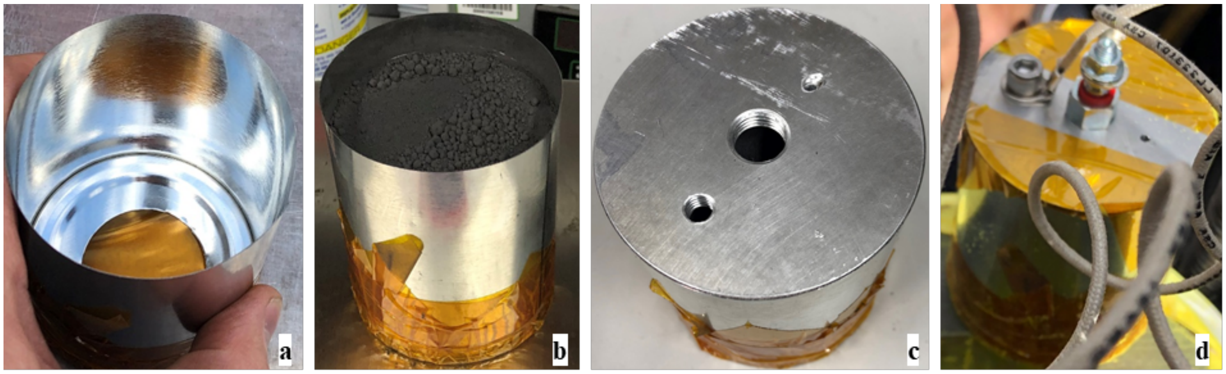

Figure 3. Thermite can for Configuration 2 used in **Hand-Tamped** Shot. Progression from empty (a), filled (b), lid placed (c) and wired (d).

Blast and fragment mitigation was afforded by a concrete block house. All of the shots were done at Point 6, TA-39 (Ancho Canyon). The house used four 5-ton 3' x 3' x 8' blocks and four 2.5-ton 3' x 3' x 4' blocks as shown in Figure 4. Three layers of ¾" plywood supported two layers of sandbags to cover the experiment.


Figure 4. Block house for blast and fragment mitigation.

Results and Discussion

Short tube shot. The tube fragments from the short tube shot showed clear evidence of detonation. The detonation was weak and the C4 shock apparently ran for several inches into the prilled material before turning over to detonation. The evidence for detonation was the deformation and fragmentation of the tube and deformation of the bottom plate. Figure 5 shows the bottom plate and debris.

Figure 5. Bottom plate and debris from the short tube shot. Note the deformation in the plate and the flare in the top end of the most-intact piece of tube.

The PDTC shot. The temperature ramp profiles for the PDTC shot are shown in Figure 6. The violent excursion is evident at 206 C and we chose the critical temperature at 196 C. Figure 7 shows a still frame from a movie. Although the reaction appeared very violent, moving the 10k# blocks several inches, the tube and its end caps were intact, indicating no detonation occurred.

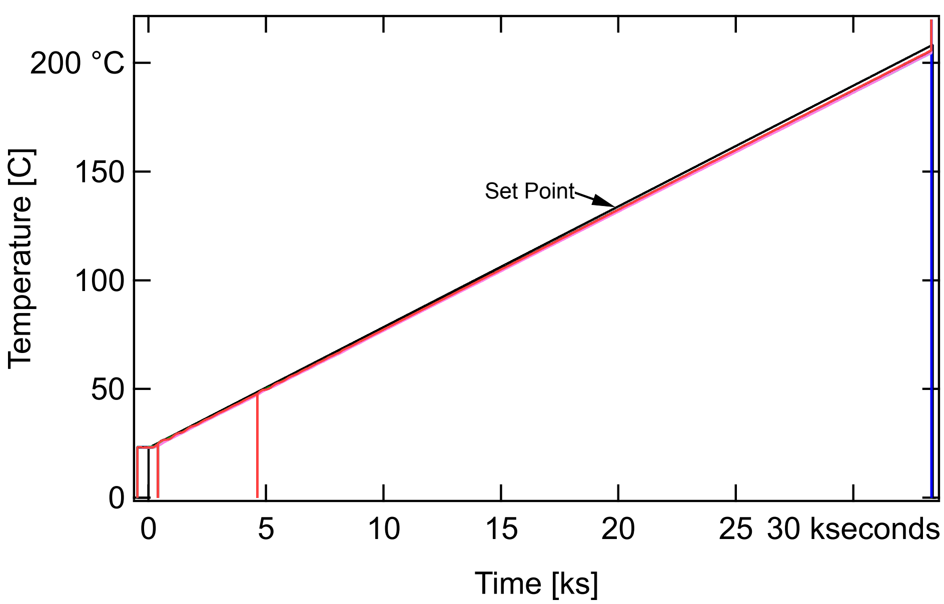

Figure 6. Temperature profiles for the PDTC shot. The excursions to the right are artefacts from the destruction of thermocouples.

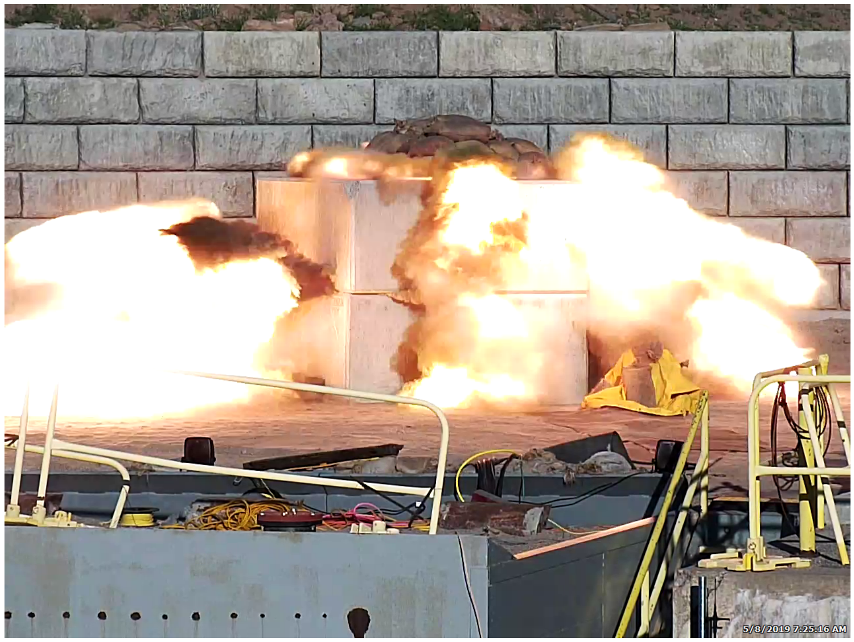

Figure 7. Still frame from the video of the PDTC shot, at peak intensity.

Figure 8 shows the tube assembly, post-shot. We hypothesize the violence resulted from reactive gasses that escaped the tube, but were trapped in the block house and subsequently ignited, or that the HE ignited near the center and pushed burning HE out of the tube.


Figure 8. Tube assembly after the shot.

The PDI shot proceeded per the dual ramp profile specified above. Figure 9 shows the heating temperature profiles. We employed the igniter Configuration 1 described above. (Figure 2). There was ullage of 4.75” measured between HE pellets and lip of tube with 390.9 g of thermite placed between HE pellets and 0.5" from lip of tube; and a thermite density of 0.79 g/cc was achieved. An elapsed time of 45 s between supplying glow plug power and ignition of thermite occurred.

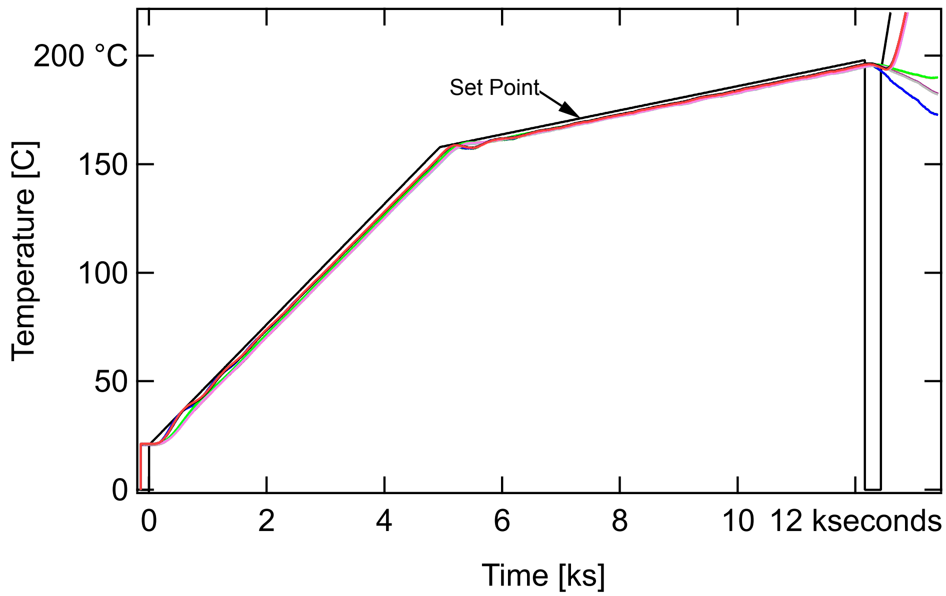

Figure 9. Heating temperature profile for the PDI shot.

The PDI shot showed no evidence of detonation. The reaction was qualitatively less violent and the tube remained intact with the end caps attached.

The pour density shot failed to ignite. We believe this resulted from settling of the extremely low density after simple pour-filling (0.28 g/cc, ~14 %TMD). Even though some thought was put into removing all ullage between glow plug and thermite, an out-of-contact geometry occurred; this indicates that the thermite pulled away ~1.25" from the glow plug. Considerable discussion resulted in the design and use of the floating igniter arrangement described above (Figure 3). Also, in the context of feedback for the test standard, our discussion led to concurrence that the standard should specify a minimum meaningful density, one that is at least detonable. We question whether or not the pour density achieved here was detonable under any circumstance.

The hand tamped density shot. Due to the failure and physics-based concerns for the pour density shot, we hand-tamped PATO into the tube at the firing point. A thorough peer review established a safe procedure for this operation and documented in an email sent May 21, 2019 by Lee Perry (M-7). A copy of this email is included as an appendix to this document. This peer review resulted in a wooden plunger 2.5" in diameter attached to a wooden handle to preclude any sparking hazards. The handle was labeled every inch allowing determination of sectional density. As such, a density of 0.39 +/- 0.05 g/cc (20 %TMD) was achieved for each tamped section. The thermal profiles were essentially identical to those shown in Figure 9, and are not repeated. The ignition system functioned successfully. As with the PDI shot, a mildly violent reaction occurred that did not significantly damage the tube or end caps: no detonation occurred.

Render safe. From the outset, a protocol was agreed upon to carry forth regarding any ignition failures and/or suspected partial reaction. This protocol was to heat the tube to 400 °C, or higher, for ~30 minutes and then allowing the tube to cool back to below the exclusion temperature (75 °C) before approaching the firing point. Thus, for each shot regardless of the outcome observed, the tube was heated to cause full reaction of any PATOVA remaining.

Summary and Conclusions

Under the extreme over-test conditions imposed by the standard, with no replicates, PATO did not undergo DDT. The short tube test also demonstrated that the hand-tamped density was a detonable configuration when sufficiently shocked. There are caveats to drawing a conclusion regarding the propensity of PATO to DDT during any stockpile scenarios, normal or abnormal. Namely, we did not do replicates. Under discussion, knowledgeable peers argued that the test was designed to such an extreme that replicates were gratuitous and unnecessary. And, the Standard calls for threaded end caps, but allows other equivalent methods. We elected to use all-thread rods to provide equivalent confinement. Examination of the tube ends, where abutted to the end caps, revealed evidence of substantial blow-by. Had we used threaded end caps, gas production would have breached the confinement at some point, but we have no way of knowing if there would have been a pressure equivalency. Finally, the standard calls for pour density. This requirement was motivated by the knowledge that a damaged explosive with high porosity has a greater propensity to DDT than one at production density (e.g. an assumed worst case). However, the standard failed to consider the lower limit of density at which any explosive will detonate, and/or have any meaningful energy if it does. With those caveats in mind, we can state a conclusion subject to the following assumptions:

- the test as specified is sufficiently extreme, such that replicates are not required;
- the choice of all-thread-affixed end-caps versus threaded end-caps did not affect the outcome (in either case, the requirement calls for venting);
- the hand-tamped density appropriately represents a worst-case configuration to promote DDT.

<u>Under these assumptions, we conclude that PATO will not DDT under stockpile conditions, normal or abnormal.</u>

Recommendations

From our experience in this first application of the new standard, we offer the following recommendations:

- the issue regarding threaded end caps versus all-thread, or other end confinement be defensibly resolved and captured in the standard;
- the need for replicates be resolved and revised in the standard if they are determined to be unnecessary;
- a re-thinking and revising of the standard regarding the non-production density configuration to reflect a worst-case but meaningful and detonable density.

Acknowledgements

Many people contributed to this report through discussion and peer review.

Gary Parker
Peter Dickson
Eric Brown
Larry Vaughan
Dennis Jaramillo
Joe Lloyd
Mandy Smith

APPENDIX: Peer Review (email)

Peer Review for Hand Tamping PATO into 3" DDT Tubes

Perry, Lee
Tue 5/21/2019 1:13 PM
To: Bowden, Patrick Robert; Leonard, Philip; Broilo, Bob; Jaramillo, Dennis C; Brown, Eric; Smith, Mandy; Lloyd, Joe; Vaughan, Larry Dean
Cc: Dickson, Peter

Reply all

All:

Thanks for the good discussion and peer review today. Per P101-8 3.2.1.c (Peer Review) the concurrence in the meeting and concurrence with this email will allow us to proceed with the operation. Overall, we agreed that if we use the proper tools and precautions, hand tamping PATO into our 3" DDT tubes is a safe operation and also consistent with DOE-STD-1212 Section 12.8 (Assembly-Disassembly). We discussed the following specific elements:

- Take precautions to keep the operation free from sand and other grit-like contaminants.
- Use a non-sparking tool with clearances to avoid pinching and friction.
- Ensure the tool is clean before using.
- Proceed by incremental fills to minimize axial density gradients.
- Clean all excess HE before assembling metal parts.
- The loader and safety-second person will wear a respirator. (Phil will consult IH)

Please let me know if this doesn't capture what we discussed and agreed on and if anything needs to be revised or added.

- Lee